Measurements of unpolarized azimuthal asymmetries in SIDIS at COMPASS

Giulio Sbrizzai
Trieste University and INFN
on behalf of the COMPASS Collaboration
Measurements of unpolarized azimuthal asymmetries in SIDIS at COMPASS

Outlook

- Introduction
- The COMPASS experiment
- Asymmetries extraction
- Results

- for completeness, also a look at Collins and Sivers asymmetries from 2007 polarized proton data
SIDIS \[ l n \rightarrow l' h' X \]
Present experimental status

\[ l_n \rightarrow l'_n h' X \]

- EMC
- E665

→ large \( \cos \phi_h \) effect (up to 40% amplitude),
  \( \cos 2\phi_h \) small (~5%)
  - no charge separation so far!
- Zeus (pQCD region)
- \( \sin \phi_h \) ~ 3% (CLAS)

PR D48 (1993) 5057
PL B481 (2000) 199
PR D69 (2004) 112
Unpolarized target SIDIS cross section

\[ d\sigma \propto F_{UU}^{\cos \phi} \epsilon_1 \cos(\phi_h) + F_{UU}^{\cos^2 \phi} \epsilon_2 \cos(2\phi_h) + \lambda_l F_{LU}^{\sin \phi} \epsilon_3 \sin(\phi_h) \]

kine factors:
\[ \epsilon_1 = \frac{(2-y) \cdot 2 \cdot \sqrt{1-y}}{1+(1-y)^2} \]
\[ \epsilon_2 = \frac{(1-y) \cdot 2 \cdot \sqrt{1-y}}{1+(1-y)^2} \]
\[ \epsilon_3 = \frac{y \cdot 2 \cdot \sqrt{1-y}}{1+(1-y)^2} \]

3 independent modulations in the hadron azimuthal distribution

beam polarization  Cahn effect, Boer-Mulder, pQCD
The origin of the azimuthal asymmetries

- First measurements were proposed as test for perturbative QCD azimuthal asymmetry due to gluon radiation (Georgi-Politzer, 1978)
- pQCD contributions expected to be important at $p_T > 1$ GeV/c

\[ O(\alpha_s^2): \]
H. Georgi and H. D. Politzer. PRL 40 (1978) 3-6
A. Mendez. NP B145 (1978) 199-220.

\[ O(\alpha_s^3): \]
The origin of the azimuthal asymmetries

• *First measurements were proposed as test for perturbative QCD azimuthal asymmetry due to gluon radiation* (Georgi-Politzer, 1978)

• *Alternative hypothesis*
  azimuthal asymmetry due to quark intrinsic transverse momentum inside nucleon, kinematical effect  (Cahn 1978)
Cahn effect

- Kinematical effect
- Leading order QED with non null quark transverse momentum (quark-lepton scattering)

\[ d \sigma^{1h \to 1'h} \propto \sum_i f_i \cdot d \sigma^{q_i \to q_i'} \cdot D_i \]

\[ d \sigma^{q \to q'} \propto \hat{s}^2 + \hat{u}^2 \]

\[ \hat{s} = (l + k)^2 \]
\[ \hat{u} = (l - k')^2 \]

- \( \vec{k}_t = 0 \)
- \( \vec{k}_t \neq 0 \)

Additional physics

(modulations in the azimuthal distributions of the hadrons)

\[ \cos(\phi) ; \cos(2\phi) \]
The origin of the azimuthal asymmetries

- First measurements were proposed as test for perturbative QCD azimuthal asymmetry due to gluon radiation (Georgi-Politzer, 1978)

- Alternative hypothesis
  azimuthal asymmetry due to quark intrinsic transverse momentum inside nucleon, kinematical effect (Cahn 1978)

- Recently, interest is renewed because they can give further informations on Boer-Mulders TMD PDF (Boer-Mulders 1998)
  - leading order PDF
  - correlation between quark intrinsic transverse momentum and transverse polarization in an unpolarized nucleon
### Transversity PDF

<table>
<thead>
<tr>
<th>nucleon</th>
<th>quark</th>
<th>U</th>
<th>L</th>
<th>T</th>
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<tr>
<td>U</td>
<td>( f_1 )</td>
<td>( g_{1L} )</td>
<td>( h_{1L} )</td>
<td>( h_1^\perp )</td>
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<td>( h_{1T} )</td>
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</table>

- **Boer-Mulders PDF**
- **Transversity PDF**
- **Sivers PDF**
(TMD) PDF

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<tr>
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<tr>
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Boer-Mulders PDF

Transversity PDF

Sivers PDF

(TMD) FF

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<td>T</td>
<td>H_1^T</td>
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Collins FF
<table>
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<td>$g_{1T}$</td>
<td>$h_{1T}$</td>
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</tbody>
</table>

**Boer-Mulders PDF**

**Transversity PDF**

**Sivers PDF**

**Collins FF**

**PDF ⊗ FF**

**in cross section:**

<table>
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(TMD) PDF

(TMD) FF
The COMPASS experiment
COMPASS
fixed target experiment
at the CERN SPS
broad physics programme

Data taking since 2002:

<table>
<thead>
<tr>
<th>muon beam</th>
<th>deuteron ($^6$LiD) polarised target</th>
<th>2002</th>
<th>2003</th>
<th>L/T target polarisation 4:1</th>
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<td>2006</td>
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<td>L target polarisation only</td>
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<td>proton (NH$_3$) polarised target</td>
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<td></td>
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<td>2007</td>
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<td>L /T target polarisation 1:1</td>
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<tr>
<td>hadron beam</td>
<td>LH target</td>
<td>2008</td>
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muon beam:  160 GeV/c
longitudinal polarization -80%
intensity 2*10^8 μ+ / spill (4.8s/16.2s)

Giulio Sbrizzai
Spin 2008 Prague, July 22, 2008
2004 COMPASS apparatus

160 GeV/c μ⁺ Beam
Polarized Beam and Target
≈80% ≈50%

$^6$LiD Target
SM1
SM2

Two stage Spectrometer
120 mrad angular acceptance

Nucl. Instr. Meth. A577 455

2002-2004: $^6$LiD (polarised deuteron)
dilution factor $f = 0.38$
polarization $P_T = 50\%$
data sample: (for this analysis)
- part of the 2004 data collected with longitudinal (L) and transverse (T) polarization
- with both target orientation configurations to cancel possible polarization effects

event selection: (for this analysis)
- $Q^2 > 1 \ (GeV/c)^2$
- $0.1 < y < 0.9$
- $W > 5 \ GeV/c^2$
- $0.2 < z < 0.85$
- $0.1 < p_T < 1.5 \ GeV/c$

final statistics: (for this analysis)
Mean values of kinematical variables

COMPASS

$\langle Q^2 \rangle$ [(GeV/c)^2]

$\langle y \rangle$

$^6\text{LiD (part)}$

$\langle p_T \rangle$ [GeV/c]

Preliminary
Asymmetries extraction
To extract the asymmetries:
the azimuthal distributions have to be **corrected by the apparatus acceptance**

→ **dedicated MC simulations** for L and T target polarization data

**initial az. distribution**

Azimuthal Distribution (0.63<z<0.85)

**final az. distribution**

corrected azimuthal distribution (0.63<z<0.85)
To extract the asymmetries:
the azimuthal distributions have to be corrected by the apparatus acceptance
→ dedicated MC simulations for L and T target polarization data

the final azimuthal distributions
are fitted with the function:

\[
N_{\text{corr}}(\phi) = N_0 \cdot \left[ 1 + A_{\cos \phi} \cdot \cos(\phi) + A_{\cos 2 \phi} \cdot \cos(2\phi) + A_{\sin \phi} \cdot \sin(\phi) \right]
\]
systematic errors evaluated from:

- compatibility of results with L and T target polarization (different experimental conditions, different MCs)

- comparison of results obtained using two different MCs with different settings for each data set (LEPTO default, standard COMPASS high pt; ~extreme cases)

- compatibility of results from subsamples corresponding to
  - different periods
  - different geometrical regions for the scattered muon
Results
\[ \frac{A_{\sin \phi}}{\epsilon_3} = \frac{y \cdot 2 \cdot \sqrt{1 - y}}{1 + (1 - y)^2} |\lambda| \]

**error bars:** statistical errors  
**red bands:** systematical errors
$A_{\cos \phi} = \frac{\epsilon_1}{\epsilon_1}$

$\epsilon_1 = \frac{(2-y) \cdot 2 \cdot \sqrt{1-y}}{1+(1-y)^2}$

**Error bars:** statistical errors

**Red bands:** systematical errors

**Cos \( \Phi \) modulation**
\[
\frac{A_{\cos 2\phi}}{\varepsilon_2} = \frac{(1-y)\cdot 2\cdot \sqrt{1-y}}{1+(1-y)^2}
\]

\[
\varepsilon_2 = \frac{(1-y)\cdot 2\cdot \sqrt{1-y}}{1+(1-y)^2}
\]

**error bars:** statistical errors  
**red bands:** systematical errors
summary:

positive hadrons

negative hadrons

error bars:
statistical only

COMPASS 2004 $^6$LiD (part)
$\cos \phi$

**comparison with theory**

![Graph showing $A_{D(\cos \phi)}^h$ vs. $x_{Bj}$ and $z$](image)

**predictions by:**

M. Anselmino, M. Boglione, A. Prokudin, C. Turk


*does not include Boer-Mulders contribution*
\[ \cos 2\Phi \]

comparison with theory

predictions by:
V. Barone, A. Prokudin, B.Q. Ma

- sum of all contributions
- Cahn effect
- Boer-Mulders
- QCD (first order)
Conclusions (I)

First results on unpolarized asymmetries from COMPASS

- $\sin \Phi$ compatible with zero

- $\cos \Phi$ stronger effect (up to 40%), $\cos 2\Phi$ up to 10%
  (good general agreement with predictions)

- Differences between asymmetries from positive and negative hadrons ($\cos \Phi$ and $\cos 2\Phi$) --> hint of B-M PDF

- New input for theoretical work and the better understanding of the nucleon structure
COMPASS results on transverse spin and transverse momentum effects on deuteron (2002-2004)

- Transversity DF
  - Collins asymmetry
  - Two hadron asymmetries
  - A polarization
- Sivers DF
  - Single hadron asymmetries
- Other transverse spin dependent PDF
  - Single hadron asymmetries

2007 proton data ...
just a flash:
Collins and Sivers asymmetries extracted from proton data (2007)

new COMPASS results shown at Transversity 2008 (Ferrara-Italy) on transverse spin and transverse momentum effects
Sivers asymmetries

Collins asymmetries

two independent azimuthal modulation in hadrons distributions
Collins asymmetry

at small $x$ the asymmetries are compatible with zero
in the valence region the asymmetries are different from zero, of opposite sign for positive and negative hadrons, and have the same strength and sign as HERMES
Collins asymmetry

COMPASS 2007 proton data (part)

${}^6$LiD target
Sivers asymmetry

The measured asymmetries are small, compatible with zero.

Statistical errors only; systematic errors ~0.5 $\sigma_{\text{stat}}$
Conclusions (II)

Collins and Sivers asymmetries for protons

- Collins asymmetry on proton target is different from zero
  the effect is there at COMPASS energies
  (transversity PDF and Collins FF different from zero)

- Sivers asymmetries smaller, compatible with zero
  these results suggest small effect at COMPASS energies
  to be understood